Indoor air quality refers to indoor pollutants that can affect the health of occupants. Until 1960s, indoor air quality in non-industrial indoor environments was not on the list of environmental problems. This table here shows the connection between the energy consumption and indoor air quality in buildings between the 1970s and the 1990s. I want to highlight two figures. Firstly, the majority of people spending up to 90% of time indoors; secondly, up to 40% of energy has been consumed by the ventilation systems and lighting in buildings. Therefore, we want to ask a question: can we make buildings both energy efficient and healthy for the occupants?

Before answering the question, let's have a look at the indoor air pollutants and their health impacts. Indoor air pollutants refer to indoor chemical, biological and physical agents that cause health threats and discomforts. This table here lists 7 indoor air pollutants, the indoor sources and the health impacts. Indicating that indoor air pollutions are mainly caused by building materials, occupants and their activities. Besides, temperature may directly affect occupant's health and comfort, where humidity can also have direct and indirect effects, i.e. the growth of microorganisms. Indoor air pollutants may be responsible for an increased occurrence of cancer; allergic diseases; infectious diseases and respiratory infections. The health and social care costs of air pollution in England could reach £5.3 billion by 2035.

Let's look at the sources of indoor air pollution at a domestic setting. Outdoor air pollutants enter the building through openings, i.e. windows, doors and cracks. They circulate within the built environment of the house and mix with air pollutants from the indoor sources. This can vary in different rooms, depending on the occupants and their activities. Some indoor pollutants may also contribute as emissions for outdoor pollution.

The project DOMESTIC stands for "domestic energy systems and technologies incubator". We aim to develop and build a facility for the demonstration of domestic technologies and design methodologies, with focus on energy efficiency and indoor air quality. There are three components - plant room, sensor unit and incubator. The sensor unit measures and records real-time energy consumption and indoor air quality in the incubator. The design of the incubator is shown at the bottom-right. It is a simplified one-bed flat, with kitchen dinner area and en-suite bathroom.

We have chosen a shipping container to be converted into the incubator, and use modular building solutions, because it is faster (30% to 50% quicker than traditional construction methods); greener (i.e. off-site construction; insulated with eco-friendly materials rockwool, which provides super thermal insulation. This means a thermal comfort inside the building can be achieved without using extra energy for heating or cooling. Windows can be used as another passive technology, which can provide natural light and fresh air, gaining heat on sunny days in the winter. Also, solar panels will be installed for the incubator as a renewable energy source. The table at the bottom-right shows the energy consumption of the incubator with listed items. A 2.4 KWp solar panel system can cover more than 98% of the energy demand, which means the incubator is a “nearly zero energy building”.

Now let’s look at the indoor air quality. First of all, compared to the well-established outdoor air quality regulations, there are limited guidelines on indoor air pollutants. Secondly, there is no standard index for IAQ, and no standard sampling strategy that specifies “when, how often, for what period of time and where samples should be taken”. However, to understand and assess the impacts of air pollutants on individual’s health, dynamic measurements and analysis on indoor air are recommended.

Thanks to the rapid development of low-cost sensors, cost-effective, portable and high-resolution data is available to monitor indoor air quality. The bottom pictures are from my MRes project on “low-cost sensors for air quality measurement”. A NO_2 sensor platform was prototyped, which can data log NO_2 concentration and meteorological factors (temperature, relative humidity and pressure) for air quality monitoring. It is light-weight (< 100 g), compact (slightly bigger than a normal mouse) and at a total cost of under £150.

Two effective measures to improve IAQ are source control and ventilation. Therefore, it is important to consider the outdoor conditions, indoor spaces and activities patterns for the ventilation strategies and indoor air quality. When possible, we often use natural ventilation, i.e. opening windows and doors. But sometimes we need to operate mechanical ventilation, i.e. cooker hoods during cooking, exhaust fans at showers. Notice that ventilation strategies may change the thermal comfort of the buildings, which may require additional energy to fix it. And that brings us back to the question: can energy efficient buildings be healthy and comfortable for the occupants?

To answer this question, we also need to explore the human factor and occupant behaviour. The figure here demonstrates the interlink between human factors and indoor environment. It is critical to integrate human-oriented design into a healthier built environment; equally importantly is to develop an awareness of green concerns and behaviours, as well as improve the flexibility in buildings to allow users to make choices. Moreover, we should also consider the relationship between the occupants’ tolerance of the building and their environmental attitudes. On the right-hand side shows an example of a questionnaire for post-occupancy evaluation, which can be used to assess the quality of the indoor environment by the occupants.

To optimize the building performance in a cost-effective and sustainable way with acceptable IAQ provides a huge challenge and opportunity for the Net-Zero 2050. Do you think it is achievable?